# Understanding, Predicting, and Enhancing the Power System Through Equipment Monitoring and Analysis

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# UNDERSTANDING, PREDICTING, AND ENHANCING THE POWER SYSTEM THROUGH EQUIPMENT MONITORING AND ANALYSIS

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## ABSTRACT

Reliability-based design, reliability-centered maintenance, and failure prevention rely heavily on analysis of devices and systems. Traditional analysis is done on a device-by-device basis with the installation of specialized equipment monitors local to the power system device. These intelligent electronic devices (IEDs) perform instrumentation and analysis of power system equipment based on specific vendor algorithms. Additionally, the equipment monitor vendor often provides human machine interface (HMI) software for use on a PC to communicate with their IED and provide additional analysis and data storage.

Although equipment monitoring often relies on specialty IEDs from many different vendors, users are hesitant to learn and maintain a unique HMI for each IED. Also, it is often necessary to collect and store the raw instrumentation values from the IEDs into a central location so that when algorithms change, the raw data can be analyzed again with new parameters. This centralized database also allows the values to be normalized and then accessed by common database tools to perform trending and prediction. Storage of data in a centralized database only has value if it is used.

To perform system-wide analysis, several factors must be addressed including instrumentation, collection, and transfer of the power system values to a centralized location, and finally application of analysis algorithms on these values.

This paper discusses the issues affecting equipment monitoring in substations today and describes two case studies of projects within utilities. The EPRI-sponsored pilot project uses equipment monitoring IED data from many vendors and equipment monitoring data within microprocessor-based protective relays integrated into one system.

## INTRODUCTION

We recognize that much of the power system equipment in use today is nearing, or has passed, its predicted operating life and that we are pushing equipment to increasingly higher levels to meet demands. To enhance the performance of existing systems and new designs we must understand the current state of the power system as well as predict future performance and new construction to increase availability and reliability. In short, it is essential that we enhance, automate, and reduce the cost of collecting and acting on decision-making information. This paper explores the concept of collecting and acting on power system data to understand, predict, and enhance power system health.

In general, we use the term “power system” to describe the collection of devices that make up the physical systems that generate, transmit, and distribute power. The terms “instrumentation and control (I&C) system” refer to the collection of devices that comprise the system that monitors, controls, and protects the power system. Innovative microprocessor-based IED developments within the I&C system have created new ways of collecting and reacting to data, and using these data to create information. IEDs are commonly used in the substation and on the pole top as dedicated protection, metering, and recording devices. When integrated together, they become a powerful, economical, and streamlined I&C system, capable of supporting all aspects of electric power protection, automation, control, monitoring, and analysis.

Power system equipment health data has traditionally consisted of the results of manual testing and monitoring of devices or in-service detected failures. Monitoring and diagnostics of equipment were often considered part of the operations and maintenance branch of the electric power provider. They were considered a routine periodic task and were rarely automated. If detected, maintenance issues were recorded and then often scheduled as part of the next periodic maintenance (PM) of the device. PMs are often performed on devices regardless of determined need and based on schedules determined by personnel availability. These PMs represent a large annual cost. Without reliable equipment health data, PM resources are sometimes misapplied.

Equipment health data have traditionally not been routinely collected (or at all) and are rarely automated. Collected information is often not used to predict maintenance schedules or to make operations or construction decisions. Data available from an integrated system of IEDs can serve many purposes including equipment health monitoring. Data for analysis include operating conditions of the power system such as metering and status, operating parameters of power system devices such as circuit breaker and transformer conditions, IED self test diagnostics. Analysis data also include archived records representing the reaction of the power system over time or to an event; these include system profiles, event reports, sequential events recorder files, power quality reports, and protection quality reports.

## THE VALUE OF EQUIPMENT HEALTH INFORMATION

A recent power system disturbance in a large midwestern city in the United States, demonstrated the value of equipment health data. One root cause of the disturbance was the age and deterioration of the power system cabling. The status of this inadequate cabling was unknown until after the event. The cable failed and the resulting blackout was actually due to a correctly operating I&C system. The system, in part built of protective relays, caused the outage in an effort to protect an overloaded transformer. The transformer was saved but the customers were left in the dark. By the time the chain of events led to the relay trip to protect the transformer, nothing else could be done. This event could have been avoided if the status of the cabling had been known sooner.

Utilities are now recognizing that the power system and I&C system assets, such as cables, transformers, breakers, and control systems, require more visibility. These assets need to be instrumented, monitored, maintained, and eventually replaced. They need to be managed both physically and fiscally.

## EQUIPMENT HEALTH INFORMATION IS ESSENTIAL TO ASSET MANAGEMENT

Efficiency, cost effectiveness, and availability of the power system depends on the ability to understand equipment health information and use it to perform immediate alarming of dangerous conditions, scheduling of predictive preventative maintenance, and trending of device and system performance over time.

Today's leaner utilities, independent power providers (IPPs), and others cannot afford to treat asset management as a periodic status check. They need dynamic equipment health data acquisition 24 hours a day, seven days a week and an integrated system of IEDs to support it.

Construction and instrumentation projects for new and existing assets need to provide a measurable return on investment. Projects need to be evaluated based on the value they provide. Each successful project must improve the bottom line with a positive return on investment and soft benefits must be assigned a dollar value. Evaluation must include life cycle cost of the asset, management of the asset, and analysis of the derived value over time.

Integrated asset management maximizes power system availability, reduces the quantity and duration of customer outages, reduces maintenance costs, enhances power system performance, optimizes maintenance tasks, and extends the life of power system equipment.

## CREATING EQUIPMENT HEALTH DATA

Many IEDs are dedicated to monitoring and recording equipment health data such as dissolved gas content, device and environmental temperature, and device operation statistics. Other IEDs, with the primary purpose of performing metering and protection, also create and provide valuable equipment health data. Concurrent power system parameters also need to be collected to provide the context for interpreting device and system diagnostics.

When integrated together, IEDs become a powerful, economical, and streamlined I&C system, capable of supporting all aspects of electric power protection, automation, control, monitoring, and analysis. The monitoring and analysis features of the system produce six kinds of data: instrumented, change-of-state, derived, diagnostic, historical, and settings.

### Instrumented Data

Instrumented data are periodic measurements of system parameters and status collected from instruments that are physically monitoring the power system, such as current and voltage transformers. The instrumented data include discrete status, dc voltages, and low-level analog inputs.

### Change-of-State (COS) Data

COS data are time stamped change-of-state data created when a change occurs. The identification of the point that changed, the time that it changed, and the status it changed to are all stored in a message. This is often referred to as a sequential events recorder (SER) message or sequence-of-events (SOE) message. These are so named because the data in the message provide information about what happened, when, and in what sequential order. This is valuable for both test confirmation and analysis of system events.

### Derived Data

IEDs calculate derived data from instrumented data and provide metering and power values. Metering data are analog values that represent power system operating conditions. Periodic metering data calculations give a snapshot of the instantaneous state of the power system. Calculation examples include integration over time, scaling, and filtering. Instantaneous and integrated values are archived periodically to provide peak and load profile historical characteristics of the system.

Metering values, such as demand and peak, are archived within the IED to create historical information about power system activity. We discuss historical data in more detail later in this paper.

## Diagnostic Data

Protective relays and equipment monitoring IEDs store information pertaining to power system device operation for analysis. Examples include the total number of operations, frequency of use, duration of control actions, interrupted current, temperatures, and dissolved gas analysis. Additionally, internal IED self-test processes create information about IED operation.

These diagnostic data provide information about the quality of both the power system and the I&C system. The unavailability of either system is minimized through immediate component failure indication. Traditional periodic device testing delays sensing of failures until the periodic test or a misoperation. In fact, during most tests the device is unavailable and some testing actually introduces modes of failure. System-wide device diagnostics allow operators and processes to compensate for failed devices.

In addition to storing and forwarding diagnostic data, the I&C system can immediately detect device deterioration and alert automatic processes or operators to prevent further deterioration. The I&C system can quickly alert operators or processes when devices are unavailable to perform, enabling quick repair or replacement.

## Historical Data

IEDs store collections of data to provide information about the reaction of the power system over time or to an event. These collections include system profiles, and event, SER, power quality, and protection quality reports. A time synchronization command from a centralized source allows all devices in the system to use the same clock value for time stamp purposes. Some system values are captured and archived periodically to enable trending analysis.

Historical report information allows analysis of the power system and the I&C system to validate or improve system design. Additionally, periodically-stored values provide a profile of system characteristics over time. Archived performance data provide information to trend device deterioration or improper configuration.

Profile data are a collection of archived metering data used to provide a historical trend. Each record contains a time stamp and present value of each profiled analog quantity. Remote users acquire these data and use them to analyze the load requirements and reactions of the power system. The data time stamp allows system-wide evaluation of the sequence-of-events from several devices. This facilitates system-wide operational and enhancement decisions like connecting additional power sources and modifying device settings.

Historical data are stored in report format and these reports are communicated to other devices automatically or on demand for additional remote processing. These reports can be quite large and take a lot of time to transmit. Although it is convenient to transfer all data on a single channel, many integration protocols do not support file transfer.

### Settings Data

Settings are the variables used to configure IED software to function optimally in specific end-user applications. Additionally, settings establish the thresholds for event and SER report trigger conditions, and act as the parameters used to archive information.

Settings information is often calculated and stored remotely and then transmitted to the IED through a communications connection. Engineers, relying on their experience or expert software tools, can work remotely to create sophisticated, coordinated settings. These settings are often needed to interpret and analyze the other data created by the IED. Examples include current transformer (CT) ratios and line impedance values.

## EQUIPMENT MONITORING IEDS

### Dissolved Gas Monitor

Dissolved Gas Monitors measure and report gas concentration levels within device insulating oil. When gas concentration levels exceed set limits, the IED creates a report, tracks, and trends historical alarm records.

### Moisture Monitor

Moisture Monitors measure and report moisture concentration levels within device insulating oil. When moisture concentration levels exceed set limits, the IED creates a report, tracks, and trends historical alarm records.

### Circuit Breaker Condition Monitor

Circuit Breaker Condition Monitors report mechanism transit time, duration of the arcs during tripping, cumulative $I^2T$ or IT on the contacts from the arcs during tripping, restrike occurrence and/or operation counts, and time/date stamping. When alarm threshold levels are exceeded, the IED creates a report, tracks, and trends historical alarm records.

### Load Tap Changer (LTC) Monitor

Load Tap Changer Monitors report load tap changer parameters, such as position, max/min changes per day, temperature, and current. The LTC also records summary data, such as load current, contact wear factors, and bus voltage.

### Protective Relay

Protective relay analysis data include operating conditions of the power system such as metering and status, IED self test diagnostics, and archived records representing the reaction of the power system over time or to an event. These records include system profiles, and event, SER, power quality, and protection quality reports. Relays also create and archive operating parameters for substation dc battery monitoring, circuit breaker monitoring, transformer monitoring, and thermal modeling.

# COLLECTING EQUIPMENT HEALTH DATA

## Communications Protocols

IEEE definition of communications protocol: a formal set of conventions governing the format and relative timing of message exchange between two communications terminals. This regulates the order and arrangement of information, transfer speed or baud rate, and error checking.

In general, power system communication networks support four basic operations: establish a communications dialogue, terminate a communications dialogue, write data, and read data. The write data function tells an IED to perform a control action, change settings, or send data to the requesting device. Each device performs error checking to determine if the message data were corrupted during transmission. The type of protocol, message format, and transfer speed are parameters that are configured during installation.

## Communications Connections

Direct connect and multidrop are the two types of communications connections available to create networks. In a direct connection, there are only two devices connected to each other. The network media, or conductor used for passing data, can be metallic, wireless, or fiber. Several individual direct connections to many IEDs allows each of them to communicate simultaneously. Many direct connections originating from one device is called a star network topology. Figure 1 illustrates the star topology.

In a multidrop network topology, several devices are physically connected in a bus or ring network, and control of the transmit and receive connection must be negotiated. Figure 2 illustrates devices connected in a multidrop bus topology. A multidrop connection requires that only one device communicate at a time. Devices on a multidrop network must speak the same protocol, have the same baud rate, and have the same physical network connection.

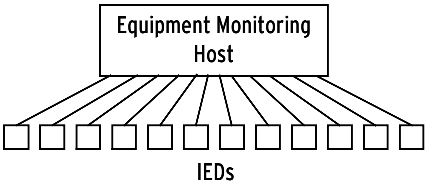

**Figure 1: Star Topology**

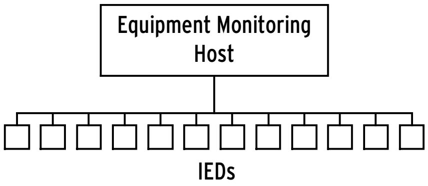

**Figure 2: Bus Topology**

Star network designs support a wide range of IED capabilities. Any protocol, including those designed for multidrop applications, are useful for direct connections in a star topology. Simple, slow communicating devices can coexist with more complex fast communicating relays. Devices from different manufacturers with different protocols can also coexist in the same star network because each has a dedicated direct connection. While features of the star topology enhance all substation integration applications, equipment monitoring applications benefit most due to the wide variety of IED types and manufacturers performing equipment monitoring.

Using a substation controller as the center of a star network further enhances the network. This allows data collected from all substation IEDs to be used to support all substation integration applications. Multiple hosts can access the data from a single substation controller as shown in Figure 3.

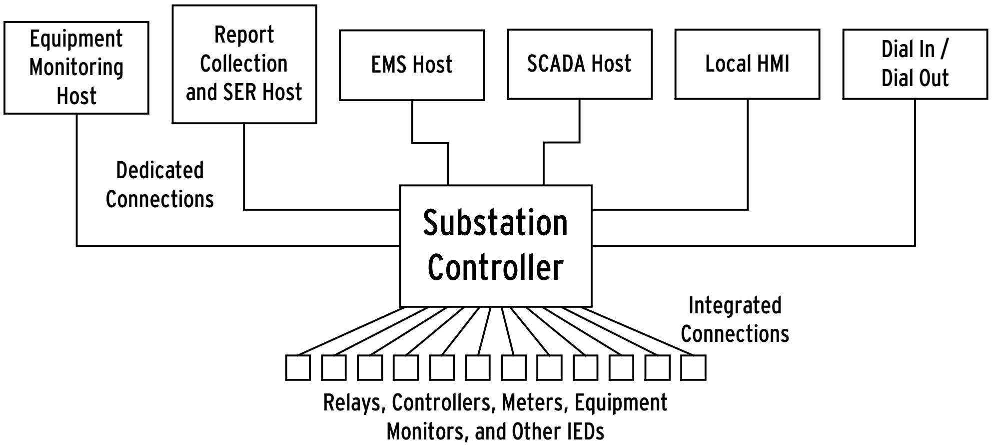

**Figure 3: Example Multiple Host Star Network**

## Dedicated Versus Integrated Communications Connections

The dedicated method requires a connection between the IED and the vendor-supplied PC software user interface. This software communicates with the IED using vendor-specific proprietary protocol. Devices are installed with the intent that dedicated communications channels support the single function of equipment monitoring. The vendor-supplied user interface collects and processes data and often provides analysis tools and data storage options. In this manner, the end user must install dedicated communications for each type of equipment and support unique software user interfaces for each vendor and/or type of equipment. Most equipment monitoring IEDs have a single communications port. Others have more but none have enough to support dedicated communications for each system application as illustrated in Figure 4. Dedicated connections do not allow the data to be used by other applications or hosts.

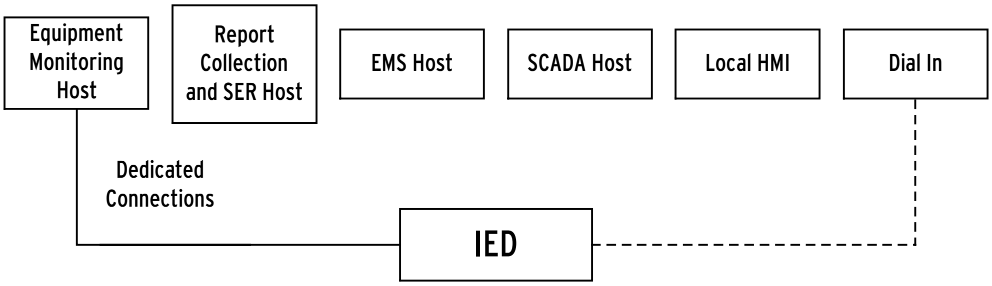

**Figure 4: Dedicated IED Connections Serve Few Applications**

The integrated approach allows a single IED connection to serve multiple purposes and supports data acquisition from many different vendors' IEDs. The integrated approach is also more flexible and adds value to the data by making it available to multiple hosts. Using the star network, a substation controller can often collect data from the IED, even if the IED was not designed to support integrated systems. A substation controller can still support the dedicated user interface connection for use with the vendors' proprietary user interface software. The difference is that when the user interface conversation is absent, the integrated approach allows the substation controller to periodically poll the IED to collect and store data in a substation controller database. The integrated approach is extremely useful given that many IEDs with SCADA or control communications connections cannot support an additional dedicated communications connection for equipment monitoring alone. With the integrated approach, the substation controller builds a supporting substation-wide database with data from each IED while supporting direct connections to the IEDs. Figure 5 illustrates a substation controller star topology serving multiple host applications.

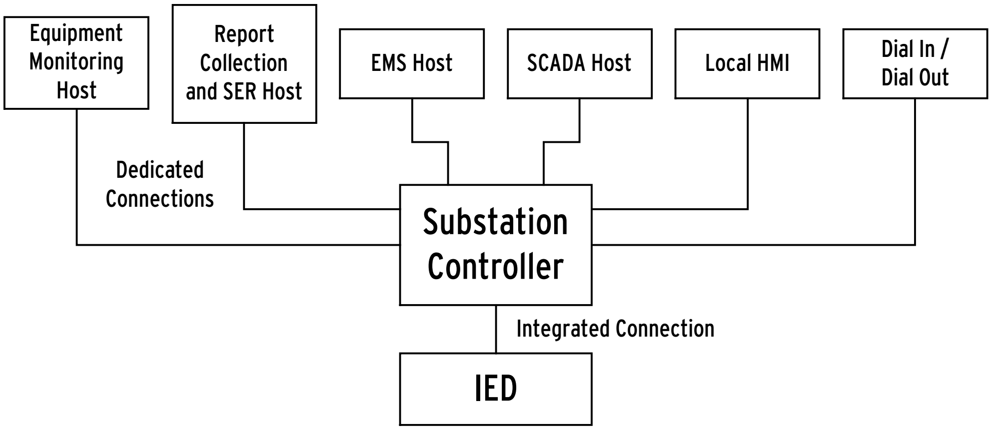

**Figure 5: Integrated IED Connections Serve Many Applications**

## BUILDING EQUIPMENT HEALTH DATABASES

Reliability-based design, reliability-centered maintenance, and failure prevention rely heavily on analysis of device and system data. This data must be collected and stored in a database for future reference and analysis. Databases support a single, specific device application or, when integrated, support system-wide analysis. Databases are created with data directly from the IEDs or with data extracted from sophisticated file formats.

The equipment monitoring host consists of a PC or other computer, communications software, user interface software, and an equipment health database. The equipment health database contains data collected from the IEDs and data created by the user interface.

### Specific Versus Warehouse Equipment Health Databases

Most equipment monitoring IED vendors provide proprietary equipment monitoring host software to communicate with their IEDs and create a database specific to their devices. These databases are designed for the data types within the vendor's product and rarely support data acquisition or data types from other vendors' products. Therefore, much the same as dedicated communications, dedicated databases are vendor-specific and require that there be a separate database for each vendor and/or type of equipment. The end user must install, understand, and maintain multiple databases and software user interfaces in the equipment monitoring host. Figure 6 illustrates an equipment host computer supporting three unique equipment monitoring hosts from three different vendors. The hosts are not interoperable and require dedicated databases, communications software, connections, and IEDs.

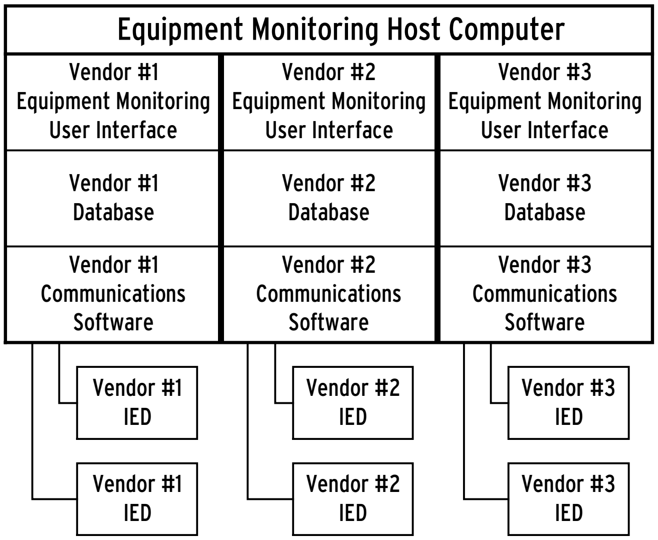

**Figure 6: Vendor-Specific Equipment Monitoring Hosts**

In the same way that a substation controller creates a substation-wide database, data warehouse applications create system-wide databases with data from multiple stations. These data warehouse applications collect and store data for use by many different end users. Revenue, administration, operations, engineering, and other departments can all access the warehouse database and each can have a user interface tailored to their needs. Using this methodology, the data is collected into and maintained at one location from many disparate sources i.e., LTCs, relays, or meters in multiple stations. The equipment monitoring host accesses the warehouse database to create information about equipment health while other departments access the same data warehouse for different purposes. This centralized database allows the values to be normalized and then accessed by common database tools. Dynamic data exchange (DDE) and object linking and embedding for process control (OPC) are two standard ways that computer applications share data. Using DDE and OPC communications software and database warehouse software from different vendors can be interoperable. These data are archived and reprocessed later if new or different analysis algorithms develop. Figure 7 demonstrates multiple hosts accessing a universal warehouse database that is acquiring data from multiple vendors via standard application interfaces.

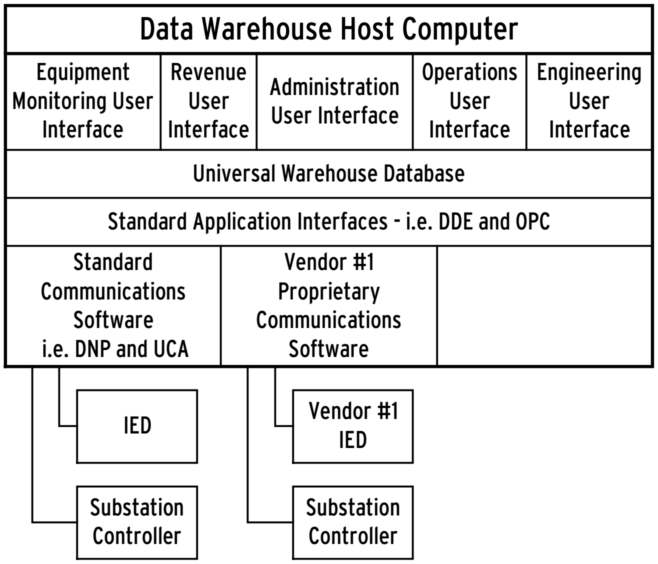

**Figure 7: Universal User Interfaces and Warehouse Database**

## Equipment Monitoring Data From Files

Protective relays and some equipment monitoring IEDs create specialized data and store them in file formats to facilitate sophisticated analysis by expert user interface applications. One such example is event record files created by protective relays to allow oscillographic analysis of power system events. The data in these files may not be readily accessible to applications other than the vendor-provided user interface. File processing software applications exist to automatically collect these files, process them, and extract summary data to incorporate into an equipment monitoring database or a system-wide universal warehouse database.

## Expert Analysis of Data From Specific Files

Expert software applications also exist to help analyze fault records to confirm proper operation of the power system components. These applications are different than conventional equipment monitoring in that they analyze recorded files rather than periodically archive values. The majority of reported events are for correct operations in which the equipment responding to the event behaved as expected. Diagnostics confirm correct operations and create maintenance alerts for equipment found to operate too near a threshold, thus preventing future failure. For those occasions when there is an incorrect operation of equipment, the emphasis is placed on the diagnostic reports which detect and identify what has gone wrong with the equipment.

The analysis data created by these file collection and data extraction applications can be added to an equipment monitoring database or a system-wide universal warehouse database. Figure 8 illustrates a universal warehouse database system receiving data from the IEDs as well as a file analysis and data extraction. The file collection and analysis software forwards data to the warehouse database.

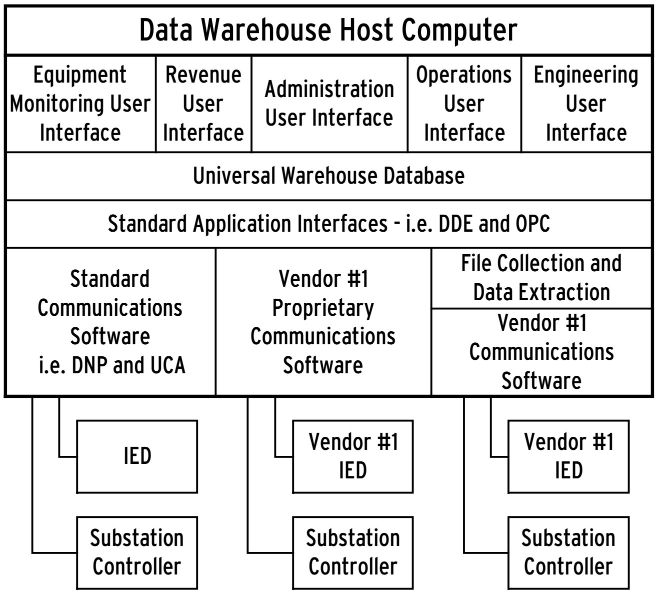

**Figure 8: Warehouse Database Populated With Extracted File Data**

## ANALYZING EQUIPMENT HEALTH DATA

Once the equipment health data reside in a database, they are further processed to determine the health quality of systems and devices. Though these data can be the source of alarm indication, instantaneous alarming is done by other faster reacting systems. Equipment health quality is recorded for reference and used to trigger maintenance actions.

Vendor-specific or universal equipment monitoring application software generally perform the analysis once the data are in the appropriate database. The equipment health data are processed into information through trending, accumulation, or simple comparison against threshold values to determine what, if any, action should be taken. Also, the addition of time-of-day, time duration, or weather conditions affords more sophisticated information.

For example, a relay and associated communications system collect and forward the magnitude of interrupt current each time the breaker operates. The relay accumulates these values and in this example the equipment monitor accumulates these values. The individual magnitudes of interrupted current mean little, but the integration of measured values indicates how much wear the breaker has likely sustained since it was last serviced. Therefore, when the integrated total magnitude passes a preset threshold value, it is determined that the breaker should be scheduled for service based on measured breaker parameters.

Sensors measure gas pressure and temperature in an SF6 circuit breaker. Condition monitors use these values to calculate gas density. The addition of time associated with measurements allows the system to process the gas leakage rate and predict when the gas needs to be replenished.

The status of the breaker “a” and “b” switch and time of change can provide an estimate of breaker operating speed. A more valuable measure is the duration time of the resulting arc. Some systems consider an arc to be extinguished when the current magnitude passes below a minimum threshold value. Thus, the arc duration time is from the beginning of current flow until the current magnitude drops below the minimum threshold. The addition of trip coil current and primary current provides better approximation of operating time and interrupter wear which indicates when a breaker needs maintenance to prevent incorrect future operation or damage.

The protective relay records the magnitude of the raw current in each phase every time the breaker opens. Some relays use this information to calculate the percentage of interrupting contact life remaining. This is similar to how a time-overcurrent element works. At every processing interval the relay measures current, runs this value through an integrating algorithm, and checks the result against some threshold. With the breaker contact wear feature, the processing interval is much longer than that of a time-overcurrent element. A breaker-specific maintenance curve defines the integrating algorithm. The protective relay also records the mechanical wear of the breaker by tracking the total number of operations regardless of the current interrupted.

Breaker compressor operation status provides the total number of compressor operations in a day. The addition of time provides accumulated total minutes of breaker compressor run time which indicates if the compressor is leaking or otherwise needs maintenance.

The total accumulated number of tap changer controller operations approximate tap changer wear. The addition of tap changer position, tap changer motor drive operating current, time, power system voltage, and transformer load voltage provide closer approximation of wear and frequency of operation. Knowledge of wear on each selector and reversing switch can be determined as well as operating duration time and confirmation that transformer voltage is being properly controlled.

Top oil temperature and primary current are the inputs to calculate simulated transformer winding temperature. The addition of the tap changer position, weather conditions, and top and bottom radiator temperatures allows modeling of expected temperature based on load and weather conditions. If the measured temperature is significantly higher than predicted, the difference indicates that the transformer cooling system is not operating correctly. These values also provide instantaneous loss-of-life and total lost insulation life values.

Transformer oil breaks down into various gases during internal transformer faults. The amount and type of gas present indicates the severity and type of faults experienced by the transformer.

The total accumulated number of voltage controller operations is used to approximate device wear. The addition of voltage magnitude indicates that the controller is operating correctly, very near thresholds, or incorrectly.

Transmission lines experience faults and protective relays react to isolate line sections. Metering values and relay target status provide information about the severity and type of fault. The addition of time permits the generation of waveform representation of metered values and allows comparison of event reports from multiple relays. Power quality data support comparison of power system operation to ideal operating conditions, and protection quality data demonstrate the fitness of the protection system to perform protection. All of this contributes to transmission line health monitoring.

IED self test diagnostics, communication system diagnostics, statistics and timing measurements, and communication network bandwidth utilization values all provide integrated communication system performance information. Overburdened processors and insufficient communications are detected and corrected.

## REACTING TO EQUIPMENT HEALTH DATA

Reaction to equipment health data is dynamic such as alarming, thus causing immediate investigation of a problem. Reaction also includes prolonged modeling of device operation, or an evaluation of system operating parameters.

The benefits of immediate alarming are intuitive and include protecting personnel and devices from harm and reducing time to troubleshoot problems. Prolonged modeling provides insight into the operation of a device or system over time. Such analysis, for example, demonstrates the degradation of a cooling system or verifies that the third reclose attempt is never successful.

The evaluation of system operating parameters provides a new world of opportunities. Rather than relying on emotion or an educated guess, equipment health monitoring provides data to substantiate operations and construction decisions. These system evaluation decisions lead to:

- Increased substation capacity through re-rating existing equipment. Equipment health data provide a technical basis for educated re-rating decisions.
- Reduced maintenance cost through appropriate maintenance and efficient use of crews. Maintenance crews use equipment health data to determine when maintenance is needed and coordinate pending tasks to make the best use of personnel.
- Increased substation performance through accurate device monitoring. Better operation of individual devices results from maintenance based on actual equipment condition.
- Reduced implementation cost through enterprise integration. Several utility departments can access a warehouse database, eliminating the need for a separate communications path and data storage system for each department.
- Improved reliability measurements through detailed system performance monitoring. Many customers now require minimum service reliability levels, for example, 24 hours a day, seven days a week. Utilities use this information to improve reliability, negotiate reliability-based rates, and verify contract compliance.
- Improved understanding of available power system capacity through system demand reporting. The power provider predicts the future needs of the system and can defer or accelerate added capacity projects while continuing to meet customer demands.

## SELECTING EQUIPMENT HEALTH MONITORING SYSTEMS

The needs of each customer are different. The best basis for selecting monitoring of any device or system requires knowledge about the devices, how they fail and how their deterioration can be monitored. The effects of the device failure must be understood, including the risk to the system, which requires risk management to prioritize and justify monitoring. It is also important to remember that the information you can and will act on is the most important data to collect. Collection of data that you have no budget to act on has less value.

# CASE STUDIES OF INTEGRATED EQUIPMENT HEALTH SYSTEMS

## Case Study #1

A large investor-owned utility in the southeastern United States created an integrated protection, monitoring, and control system made primarily of protective relays. Weather stations, battery monitors and communications processors complete the I&C system. Among other functions, this system performs protection, substation automation, distribution automation, SCADA, equipment monitoring, and allows dial-up access to every device. The communications processor collects data from the IEDs and forwards the data to a substation PC and to a transmission SCADA system. The substation PC performs substation automation, provides a user interface, and acts as a data buffer, or remote node, for a universal warehouse database at the general office. Within the PC, substation data from the communications processors are transferred to the data buffer software via DDE. This data buffer software is so called because it buffers acquired data when general office communications is lost and forwards it when communications is restored. The substation data buffer software communicates over a wide area network (WAN) connection to a workstation computer at the general office. This workstation computer acts as the universal warehouse database by executing data server software. Data queries are performed with universal tools in the substation like Microsoft® Excel software on the data buffer database or on the warehouse data server. Several departments in the utility access the data in the warehouse data server with specific user interface software applications and WAN connections to the workstation computer. One such software program is a maintenance manager application that knows equipment location, PM schedules, and workforce allocation and automatically creates work orders. This maintenance manager application brings the equipment health data full circle by providing maintenance work orders to personnel to test or repair devices based on their condition and monitored operating parameters. Intranet web access is also provided via the WAN to provide remote user interfaces to the equipment health data and SER.

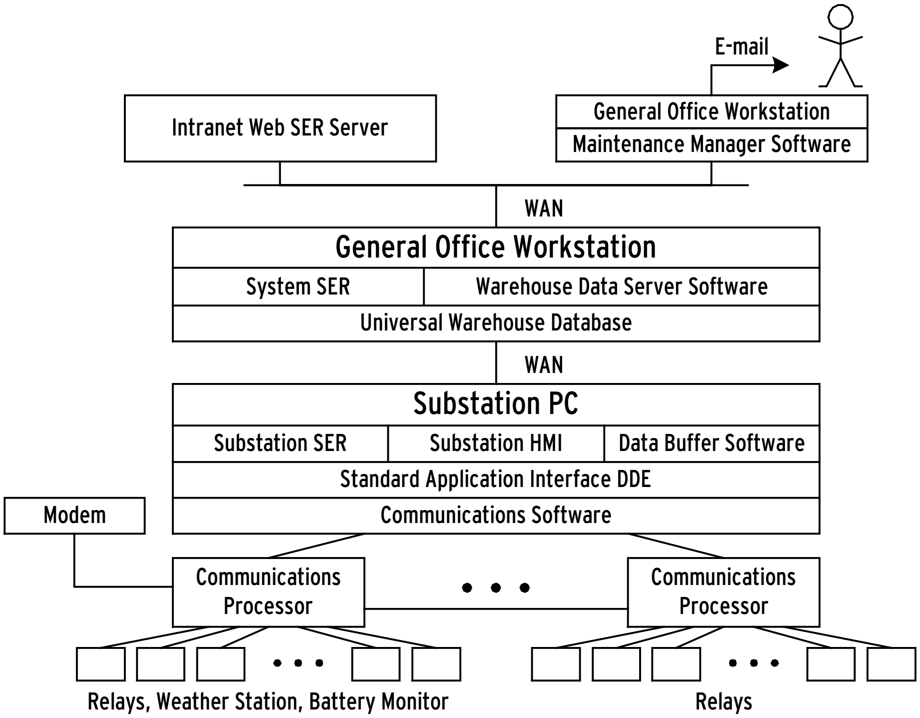

Figure 9: Case Study #1

**Case Study #2**

A utility located in the midwestern United States is currently installing an integrated equipment monitoring system using protective relays, dissolved gas monitors, LTC monitors, transformer top oil sensors, circuit breaker monitors, and communications processors. This system is separate from the SCADA and automation systems; it performs only equipment monitoring and allows dial-up access to every device. The data are collected from the IEDs by the communications processor which is using vendor-specific protocol for each device. It is, therefore, speaking to 10 different kinds of IEDs using five different protocols. The communications processor then forwards all of this data to a substation PC via DNP 3.0 protocol. In this manner, the PC needs only to communicate with one communications processor, acting as a substation controller, using one standard protocol to retrieve data for all 21 IEDs. The substation PC uses the standard application interface OPC to communicate between DNP 3.0 communications software and an off-the-shelf HMI software package and database. A maintenance management software application works directly on this database to perform the trending and analysis. Alarms created by the HMI or maintenance manager software are e-mailed to operators, maintenance requests are e-mailed to maintenance staff and to a human resources scheduler application that automatically creates work orders.

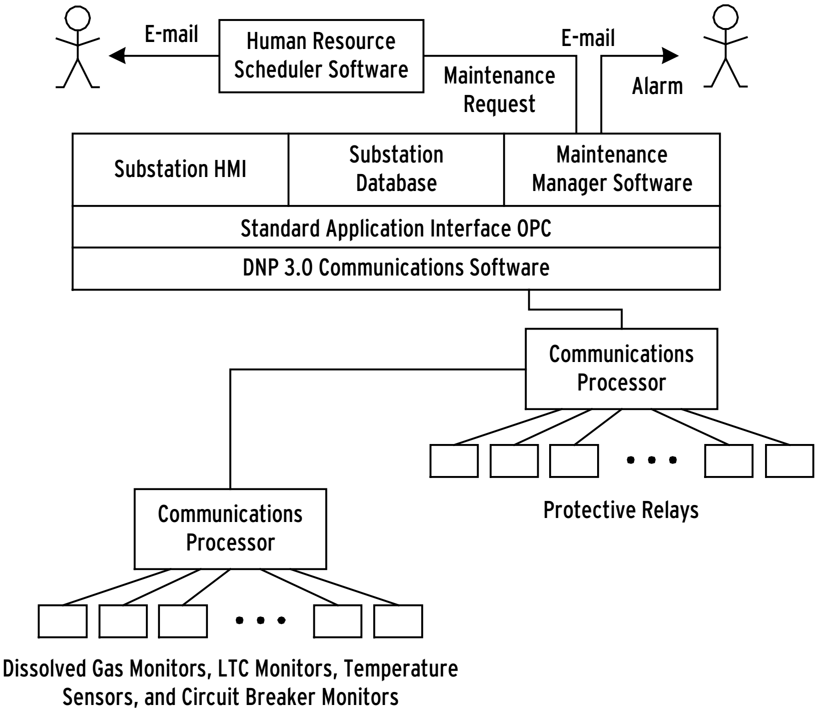

**Figure 10: Case Study #2**

## CONCLUSIONS

As with all system technology, the proof is in the implementation. One utility's experience during a recent ice storm demonstrates additional values of equipment monitoring and data warehousing. System load was high when they lost a feeder. Within moments after the event the operator on duty was able to review system conditions. The operator performed an ad hoc query within an Excel spreadsheet to look at the load conditions prior to the failure. This aided them in restoring the feeders through ties since they were unable to restore their 13 kV busses. The spreadsheet was also used to look at historical station load to determine the amount of load the station would have on a typical Monday. This information was used to determine the number of transformers needed in service to carry the station. The utility felt certain they avoided additional potential failure because they were able to identify and review system load conditions before restoring the circuit.

Equipment health data helps us understand, predict, and enhance the power system. Asset management of power system and I&C devices is accomplished through reliability-based design, reliability-centered maintenance, and failure prevention to increase system availability.

## BIOGRAPHY

**David J. Dolezilek** received his BSEE from Montana State University in 1987. In addition to independent control system project consulting, he worked for the State of California, Department of Water Resources, and the Montana Power Company before joining Schweitzer Engineering Laboratories, Inc. in 1996 as a system integration project engineer. In 1997 Dolezilek became the Director of Sales for the United States and Canada, then moved on to serve as the Engineering Manager of Research and Development in SEL's Automation and Communications Engineering group. In 2000, Dolezilek was promoted to Automation Technology Manager to research and design automated systems. He continues to research and write technical papers about innovative design and implementation affecting our industry, as well as participate in working groups and technical committees. He is a member of the IEEE, the IEEE Reliability Society, and the International Electrotechnical Commission (IEC) Technical Committee 57 tasked with global standardization of communication networks and systems in substations.

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